Preliminary Results of SIGRIM CD-Recordable Media Study

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Introduction

Over the past three years CD-Recordable technology has evolved from a test disk production capability to a storage medium that can compete with magnetic tape and optical disk in almost any storage task. It is increasingly being looked upon as an excellent archival media with an estimated storage life on the order of 100 years. The emergence of massive jukebox storage systems with hundreds of disks and multiple players will allow near line access to gigantic terabyte archives over the next year or two. [The DDL already has the complete collection of Planetary CD-ROMs (240 disks) accessible via client/server software on the INTERNET.] We expect that government agencies will invest hundreds of millions of dollars in recordable media during the remainder of this decade and feel it is imperative that we understand the characteristics of media, recorders and test devices before making this large investment.

Earlier studies of CD-ROM and CD-Recordable media have generated some puzzling results. First, the test results on the same disk from different test devices were often inconsistent. Second, test devices reported permanent errors which did not seem to effect the readability of the disks. Also, anyone who has used CD-Recordable media is familiar with problems in reading some of these disks on some CD readers. It is important that both the media industry and the recorder and reader vendors understand the interaction of media, recorder and reader to produce reliable CD-Recordable disks.

Evaluation Procedure

Vendors were asked to donate 30 pieces of 63 and 74 minute media, preferably from different batches. The Data Distribution Lab records 3 pieces of media on each recorder setup, where the recorders are Sony at 1X (single speed), Sony at 2X (double speed), Kodak (Philips) 2X and JVC 1X. As each disk is recorded a log is kept including the time, date, recorder, and environmental conditions (temperature and humidity). Each piece of media is placed in a Univenture sleeve and labeled with serial number, recorder, etc. When a number of disks are ready they are boxed and sent to one of three test sites:

- National Institute of Standards and Technology (NIST) - CD-CATS SA3
- National Technical Information Service (NTIS) - CD-CATS SA2
- Naval Air Warfare Center (NAWC) - CD-CATS SA3

These sites test each disk in the batch and send the batch on to the next site. The test results are sent to the DDL in either hard copy or floppy disk format. The electronic results from tests done by NIST and NAWC have been captured in an EXCEL spreadsheet which is available for downloading in one of several formats on the INTERNET or from the SIGCAT Bulletin Board (See Appendix B). These results comprise a table of about 100 values for each test performed.

Ongoing efforts include reader tests and longevity testing. Many of the disks which exhibit peculiarities will be tested on a variety of readers to determine reader differences, as well as the effect of various parameters on readability. A subset of the recorded and unrecorded disks will be sent to NIST for testing in hazardous environments and for accelerated aging tests.

Test Device Comparisons

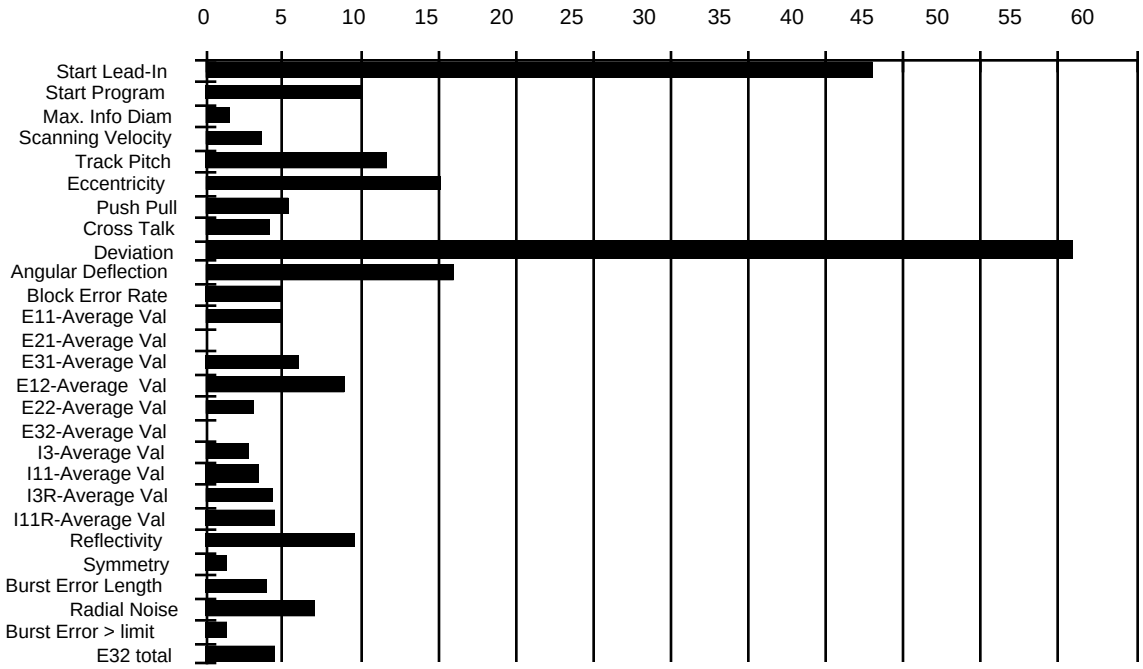
Before attempting to interpret the results of the CD-CATS tests it is important to have some confidence that the results are accurate and repeatable. The CD-CATS device reports a large number of parameters describing the physical characteristics of the disk, pit geometry and the quality of the recorded signal. These parameters are described in Appendix A. The device also provides the location on the disk where certain minimum and maximum values were encountered.

In general the values reported by all three devices are very consistent. Out of 49 disks tested on two CD-CATS SA3 devices only 2 disks show substantive contradictory results. In one case the NIST device shows permanent errors (E32) which the NAWC device does not detect, in the other case the reverse is true.

For the 98 sets of test results the average percent deviation of all measured parameters has been calculated, based on the range of values measured for the parameter. A chart for a subset of the parameters is shown in Figure 1. The greatest differences are for start lead-in area and deviation which show about 50 percent differences in values measured by the two testers. Values for track pitch, eccentricity, angular deflection, and reflectivity vary in the range of ten to twenty percent. Values for maximum information diameter, scanning velocity, push pull, cross-talk, block error rate, the specific error types (E11, E21, etc), and signal strength (I3, I11, etc), symmetry, burst errors and E32TOT vary by about five percent. The values for the locations where minimum and maximum measurements were encountered range from 6 percent to 30 percent, with the best correlation between the locations of minimum and maximum error counts.

For 29 disks we also have tests performed at NIST using different CDs to calibrate the CD-CATS device prior to performing the tests. In addition to calibrating with the standard aluminum CD-ROM disk, a Kodak CD-Recordable disk was used to perform the calibration. Of the 29 disks tested, two show substantive differences in measuring burst errors and E32s. Other values compare closely, with the exception of the location values as was the case in the test device comparisons.

Figure 1 - Percentage Differences of Tested Values



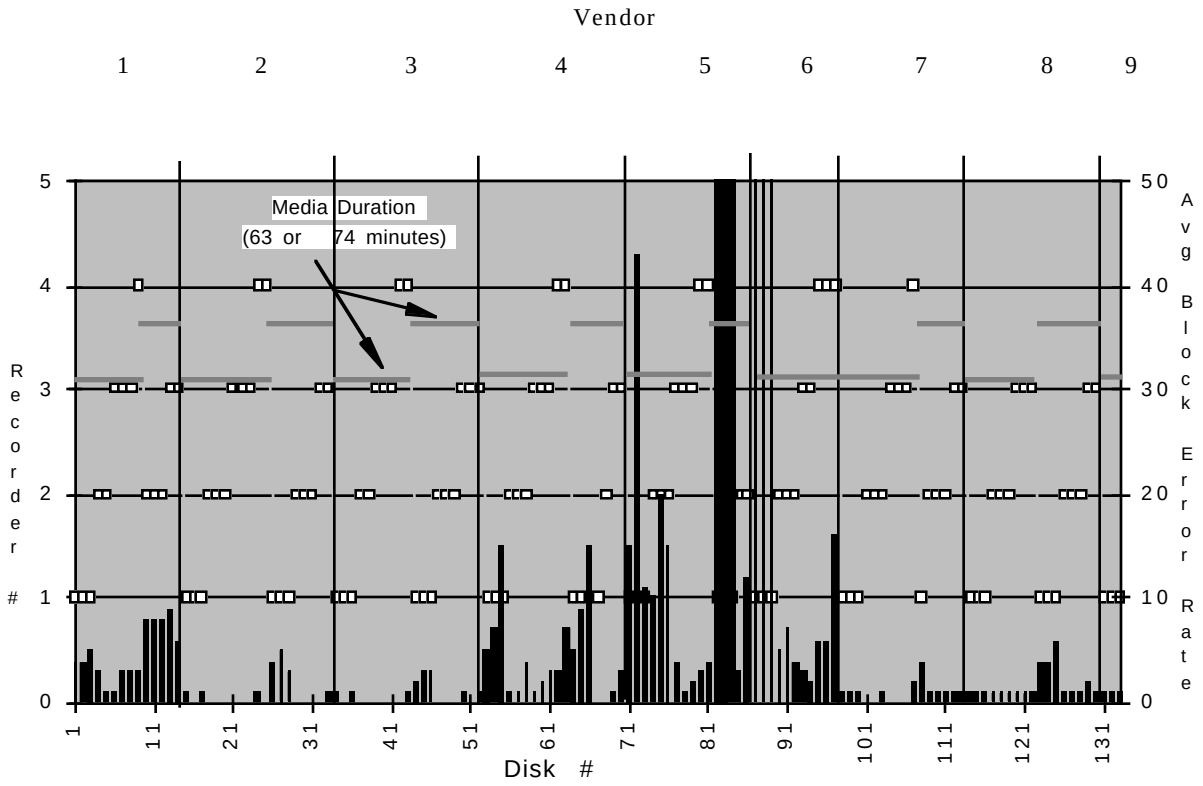
In conclusion, although there are definitely differences in the results provided by different test setup or test devices, the general results are very consistent, given the sensitivity of the test device.

Preliminary Observations from Test Results

In general the quality of the CD-Recordable media evaluated thus far is very good. The average block error rate is lower than that found on many pressed CD-ROMs. Figure 2 summarizes the average block error rate for the 136 disks tested so far. Several relationships are expressed in this figure, including the vendor, recorder and media duration. The scale on the right side gives the Average Block Error Values. The recorders are 1) Sony 1X, 2) Sony 2X, 3) Kodak, 4) JVC 1X. It can be seen that disks recorded on the Sony Recorder at 1X tend to have higher block error values, especially in the case of Vendor 5 and 6. This media / recorder incompatibility needs to be addressed by the vendors.

Other observations are noted in Table 1, which itemizes the test results on a parameter by parameter basis. Parameters which need more scrutiny are the below guideline reflectivity values for nearly all disks and high values for push pull. Several other relationships are important to evaluate including the differences between 63 and 74 minute media, the location of the majority of errors on the disks and the existence of spurious permanent errors (E32s).

Figure 2 - Summary of Average Block Errors for all disks tested.



The average BLER of 74 minute media for all disks is about double that found on 63 minute disks. However this parameter turns out to be directly related to the recording device. If the disks recorded with the Sony at 1X are excluded from the average the 74 minute media has a lower average block error rate than the 63 minute media (2.3 Vs 2.8).

It has been assumed for many years that recording out to the edge of CD media could be dangerous. The Planetary Data System has generally limited its disks to 650 megabytes due to this perception. The results of this evaluation do not support such a policy, nearly fifty percent of all errors occur in the first ten minutes of the disks tested.

Media recorded on the Kodak recorder shows a batch of E32s (usually 103 or 104) located at the beginning or the end of the disk. This also happens with a few of the disks recorded on the JVC recorder. This is apparently due to the recording strategy of some recorders which lays down the CD image first, then writes the lead-in and lead-out areas. If there is a small error in positioning, some of the first blocks or last blocks of the CD image can be over-written. This condition does not seem to affect the readability of the data contents because the blocks that are overwritten are pad blocks.

One other item of note, the duration of different vendor's media is slightly different. Do not plan to record a full 63:00 minutes of data on most 63 minute media. We had to use two separate image files for recording the 63 minute media and 3 files for recording the 74 minute media. The overhead added by different recording systems seems to vary slightly. The duration values reported by the CD-CATs device varied depending on the recorder used to write the media, (eg. the same image recorded on the Sony is reported as 63:01, Kodak - 63:00 and the JVC - 62:58. The same is true of 74 minute media. The data contents of this image file is 62:54.54).

Acknowledgments:

I would like to thank all the media vendors for contributing media for this study and Kodak for loaning us a recorder. I also thank Jerry McFaul and Dave Traudt of the US Geological Survey; Al Betts and Bethany Andrews of the National Technical Information Service; Fernando Podio of the National Institute of Standards and Technology; Tim Naugle and Ron Kushnier of the Naval Air Warfare Center; and Kristy Marski and the rest of the DDL Staff for their support of this preliminary media evaluation work.

Table 1 - Test results summary

Value	Guideline	Comments
Start Lead In (mm)	<46	All disks meet guideline.
Start of Program (mm)	46.6-50.0	Five disks low, recorded on Sony 1X.
Max Info Diameter (mm)	113	All disks exceed the guideline.
Scanning velocity (m/s)	1.2-1.4	Six 74m and three 63m out of spec.
Track Pitch (microns)	1.55-1.70	One disk out of spec.
Eccentricity (microns)	<40	All disks meet guideline.
Push pull	.045-.090	18 disks from vendor 4 exceed spec.
Cross talk (percent)	<50	All disks meet guideline.
Deviation (mm)	+-.20	Three values exceed, test device dependent.
Angular Deflection (deg)	1.6	All disks meet guideline.
Block error rate avg	<50	6 disks exceed 50, all recorded Sony 1X.
Block error rate max	<100	12 disks exceed 100, 9 recorded Sony 1X.
Reflectivity (percent)	>70	Very few disks exceed 70.
Symmetry (percent)	+-15	All disks meet guideline.
Radial noise (nm)	<15	24 disks exceed guideline, 21 recorded on Sony at 1X.
Burst error length	7	19 disks exceed guideline.
Burst error GT than limit	0	24 disks exceed guideline.
E32Tot	0	14 disks have E32s, 8 recorded on Sony 1X.

Appendix A. CD-CATS Parameter Definitions.

Start Lead-in	- Location of start of lead-in area.
Start Playable Diam.	- Location of beginning of data area.
Max Info Diameter	- Location of end of data area.
Scanning velocity	- Speed at which the track moves by the laser beam.
Track pitch	- Distance from one track to the next.
Eccentricity	- Measures deviation of tracks from perfect centering about the hole in the disk.
Push Pull	- Measure of the horizontal variance of track position making it hard to track.
Cross talk	- Measure of the track signal Vs the signal between tracks.
Deviation	- High deviation causes focusing problems.
Angular Deflection	- Radial deflection of light beam due to skew causes loss of signal.
Block error rate	- Measure of the number of blocks per second which have errors (either correctable or uncorrectable) at the first decoder.
Reflectivity	- Measure of light returned by reflective layer of disk.
Symmetry	- Measure of ratio of the shortest and longest pits and lands on the disk.
Radial Noise	- Measure of poorly defined pits or damaged tracks.
Burst error length	- Number of consecutive burst or cluster errors at the first decoder.
Burst error GT than limit	- Number of occurrences of 7 or more burst errors.
E32Tot	- Number of uncorrectable errors at the C2 decoder. Results in a error which must be corrected by layered error correction.

Appendix B - Test Data Files

The test results are stored in several files on an anonymous FTP server named starhawk and will also be loaded on the SIGCAT bulletin board. Two file formats are stored, a comma separated value (CSV) which can be imported into most spreadsheets and statistical programs and a Microsoft Excel version. To access the files on INTERNET, FTP to starhawk.jpl.nasa.gov. Change directory to "pub/cdrtests" and download the CSV files with ASCII protocol or the XLS file with a BINARY protocol.

1. For 49 disks we have tests from NIST and NADC on CD-CATS 3 testers. These tests are stored in TESTDIFF.CSV and TESTDIFF.XLS.

2. For 29 disks we have tests from NIST using Aluminum and Kodak calibration disks. These results are stored in CALDIFF.CSV and CALDIFF.XLS.

3. For 136 disks there is a summary which contains one entry for each disk. These tests are stored in SINGLE.CSV and SINGLE.XLS.

4. There is a table which contains all 225 tests that are available in machine readable format (some NTIS tests are only available in hardcopy format). These results are stored in ALLTESTS.CSV and ALLTESTS.XLS.